N87-24277

MECHANISMS FOR THE CIRCULAR POLARIZATION OF ASTROPHYSICAL OH MASERS IN STAR-FORMING REGIONS AND THE INFERRED MAGNETIC FIELDS

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Abstract

Results of further calculations to explore the cause for the circular polarization of astrophysical OH masers in regions of star-formation are presented. New calculations are given for both the non-linear, Zeeman overlap mechanism and the Cook mechanism. The authors previous result that magnetic field strengths of a few milligauss or greater are required still survives.

Introduction

A striking feature of astrophysical masers is the strong, net circular polarization of the OH masers associated with regions of star formation. Linear polarization is also common though not so prominent as the circular which exceeds fifty percent in perhaps half of the masers (see, e.g., Reid and Moran 1981 for a review). One might reasonably suspect that, in addition to gaining an understanding of a widely observed astrophysical phenomenon, a quantitative knowledge of the mechanism might yield valuable information about the structure and physical conditions in the gas in regions of star formation. Although the striking polarization characteristics of these OH masers have been recognized for some twenty years, no cause for the polarization has been established by detailed calculations. The Cook mechanism (Cook 1966), which depends upon the accidental matching of the gradients of the velocity and the magnetic field, has been a possibility. The widespread occurence of the necessary correlations in the magnetic and velocity fields would seem to be surprising, however. We (Deguchi and Watson 1986) have recently recognized an entirely new physical mechanism -- the non-linear effects of the overlap of Zeeman components caused by a velocity gradient -- and have obtained a quantitative formulation utilizing the Sobolev approximation. In the presentation at this meeting, we extend our exploration of the polarization properties of OH masers by presenting additional results for the Zeeman overlap mechanism and results from an initial formulation of the Cook mechanism, also utilizing the Sobolev approximation. Calculations are performed for an angular momentum J=1-0 transition which is expected to be representative.

Non-Linear Effects in the Overlap of Zeeman Components

In this section, we augment our previous study (Deguchi and Watson 1986) by presenting results in Figure 1 for the two linear Stokes components Q and U as a function of the strength of the magnetic field. A description of the calculations is contained in our previous paper. The calculations of Figure 1 suggest a tendency at $\Delta\nu_Z \gtrsim 1$ for the circular polarization V to exceed the

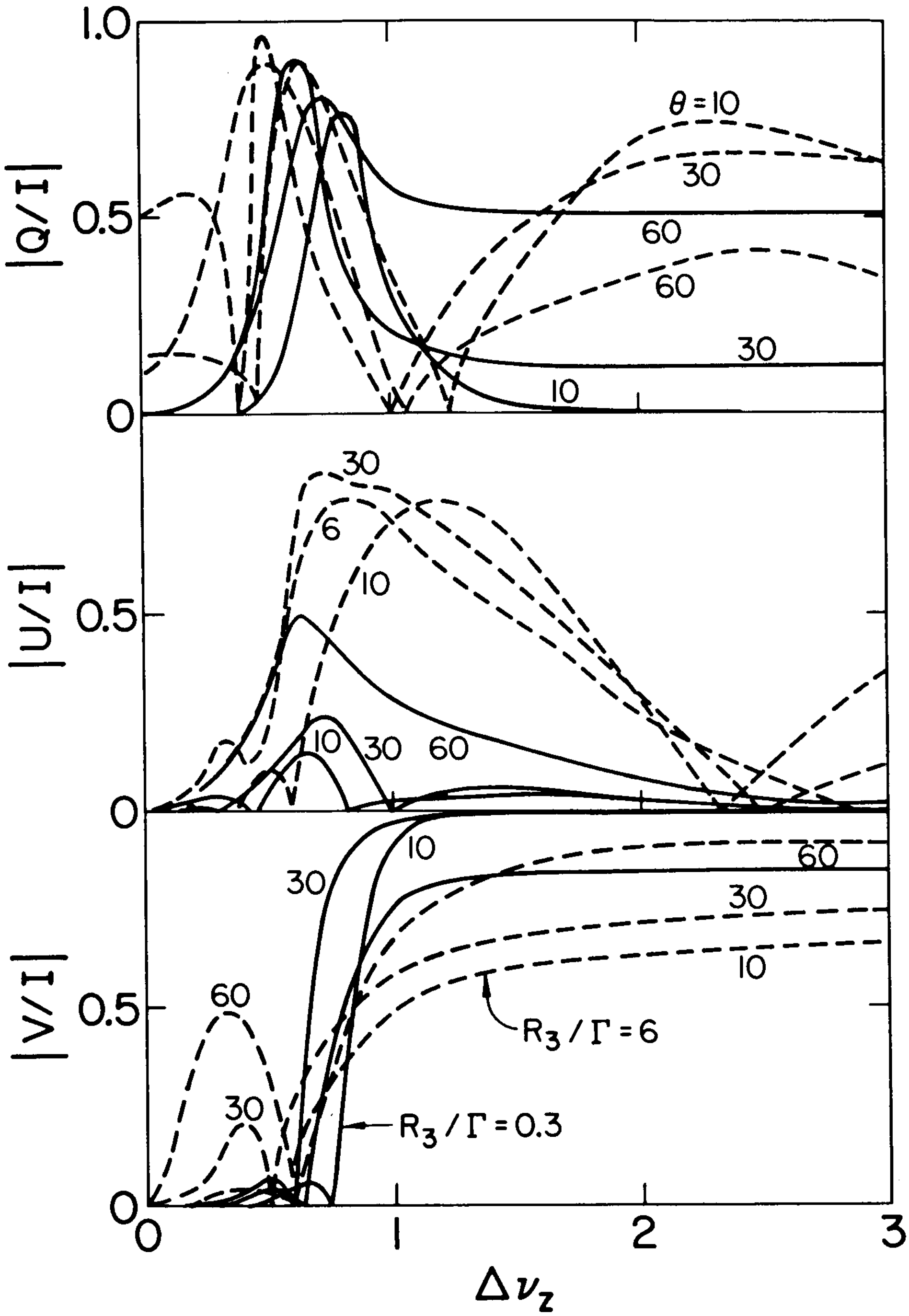

Figure 1. Ratios of the Stokes parameters Q, U and V to the intensity I as a function of the ratio $\Delta\nu_Z$ of the Zeeman splitting to the local breadth of the spectral line. The angle between the magnetic field and the axis for the velocities is designated by Θ. Solid and dashed lines give the degree of saturation R_3/Γ for the most saturated transition of the Zeeman triplet.

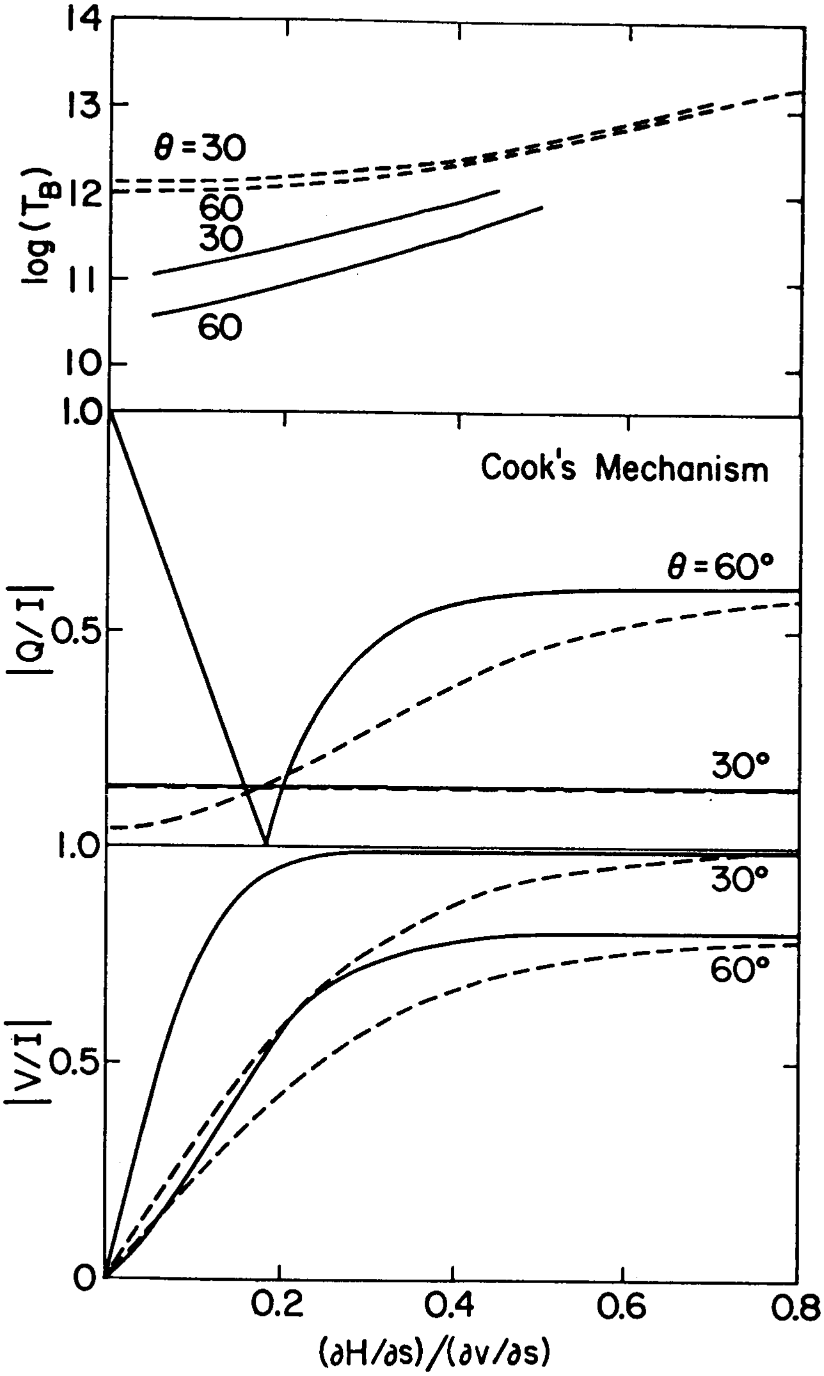

Figure 2. Calculations for the Stokes parameters and for the brightness temperature T_B (in Kelvins) viewed along the velocity axis. Quantities are given as a function of the ratio of the spatial derivatives, along the velocity axis, of the magnetic field and of the velocity in units of $(cg\mu_m/h\nu_o)$. Here, g is the Landé g-factor, μ_m the Bohr magneton and ν_o is the rest frequency for the transition. The dashed and solid lines represent different pump rates; they give the same (R_3/Γ) as in Figure 1 for $(\partial H/\partial s)/(\partial v/\partial s) = 0$. All three lines are summed to produce this Figure.

strength of the linear components Q and U -- a result that is in harmony with the observations of OH masers. This seems to be especially the case for the lower degree of saturation (R_3/Γ). Of course, the chief new information derived from the association of this mechanism with the observations is a measure of the strength of the magnetic field which is based on the requirement from Figure 1 that $\Delta\nu_Z \gtrsim 1$ to obtain large fractional polarizations. For the parameters of the OH masers, this implies magnetic fields of a few milligauss or stronger in these condensations in the gas in star-forming regions.

Evaluation of the Cook Mechanism

To our knowledge, the Cook mechanism for the circular polarization has not been evaluated quantitatively -- that is, transfer equations for the maser radiation have not previously been solved to exhibit the effect. In Figure 2, we present the results of such calculations, again utilizing the Sobolev approximation as described in Deguchi and Watson (1986). A qualification is necessary. The ideal matching of the gradients of the magnetic field and of the velocity corresponds to $(\partial H/\partial s)/(\partial v/\partial s) = 1$ in our units. The Sobolev approximation can not be used at exactly this value because the spectral line is not shifted out of the local, resonance profile by the gradients. In our calculation, the three components of the J=1-0 Zeeman triplet are considered to be so widely separated that they never overlap.

The calculations thus tend to support the idea that the Cook mechanism can be operative at the necessary maser power, given the proper correlations between the gradients of the velocity and magnetic field. What is perhaps surprising is its effectiveness over a wide range (not completely delineated here) of values for the ratio of the relevant gradients. This tends to improve the statistical likelihood for its occurence. However, the Cook mechanism (just as the Zeeman overlap mechanism) requires that the Zeeman splitting be comparable with or greater than the local breadth of the spectral lines; that is, $\Delta\nu_Z \gtrsim 1$ from Figure 1 and the limits of at least a few milligauss for the magnetic fields still hold (cf. Cook 1975).

The authors' research has been supported by the National Science Foundation.

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